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PERFORMANCE PREDICTION FOR THE DESIGN OF A VARIABLE SPEED COMPRESSOR

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ABSTRACT

Thermodynamic and dynamic analyses of a variable speed reciprocating compressor have been conducted to investigate performance changes and some data related to the reliability problems such as valve velocity, PV value, bearing loci, Sommerfeld number, minimum film thickness etc. The first law of thermodynamics, continuity equations, valve dynamic equations and Helmholtz resonator method were used in the thermodynamic analysis and lumped mass method, hydrodynamic lubrication theory and mobility method are adopted in the dynamic analysis. Simulation results for the operating speed range of 1800 to 4200 rpm will be presented in this paper.

INTRODUCTION

Recently, the reciprocating compressor with variable speed control starts to be used in the household refrigerator. Since a refrigerator with variable speed compressor could use the capacity modulation technique, it will consume less energy compared to the conventional refrigerators operating in on-off mode by using the smaller capacity compressor, reducing the refrigerant circulation rate, enhancing the heat exchangers' performance and the significant improvement in the operating conditions. For the design of the variable speed reciprocating compressor, it will be necessary to investigate the impact on the performance and reliability of the operating speed variation. A numerical simulation would be a useful tool in the analysis of these impacts.

This paper deals with a numerical prediction of the performance and reliability to present the basic design data for the development of a hermetic reciprocating compressor driven with variable speed control. A mathematical modeling including thermodynamic and dynamic analysis has been performed. Simulation results related to the performance and reliability are presented herein.

MATHEMATICAL MODELING

A compressor for R134a with swept volume of 8.7cc has been selected for the simulation. Fig. 1 shows the structure of the model compressor

Thermodynamic modeling

For the prediction of the gas property changes in the cylinder control volume, energy and mass conservation laws were used. Leakage through the clearance between the cylinder and piston was calculated using the Krueger's experimental analysis result. Heat transfer rate between gas and cylinder wall was evaluated using the Adair's correlation. Mass flow through the valves was assumed as on dimensional isentropic flow and valve dynamic motion was modeled as one-dimensional mass-spring-damper system. Gas pulsation in the muffer systems was analyzed by the Helmholtz resonator model. The suction system was modeled as three resonators in series with anechoic pipe and the discharge system was modeled as two resonators in series with anechoic pipe.

Dynamic modeling

Lumped mass method was used to determine the compressor forces and driving torque acting on the compressor mechanism. The friction losses at piston-cylinder bearing and thrust bearing were calculated using the hydrodynamic lubrication theory. For the analysis of the dynamically loaded journal bearings such as crank pin bearing and crank shaft bearing, mobility method was adopted. The mobility components were calculated from Goenka's curve fit expressions. The friction loss at the ball-joint bearing was calculated using the boundary lubrication theory.

INPUT DATA

The operation pressure follows the ASHRAE standards for the low back pressure operation. Natural frequencies of the valves were obtained from FEM analysis. Leakage ratio variation with operating speed was adopted from Krueger's experimental analysis result. The experimentally measured motor efficiency at each operating speed was used as input data in the calculation of the total input power. Fig. 2 shows the leakage ratio and motor efficiency used in this paper. According to the Krueger's results, the leaked mass flow remains constant independently of the operating speed, therefore the leakage ratio to the total cooling capacity becomes relatively higher at lower speed operation. Motor shows higher efficiency at the higher speeds.

SIMULATION RESULTS AND DISCUSSION

Fig. 3 shows the cylinder pressure change during a cycle. This result shows that cylinder pressure loss is bigger at higher operating speed because of the increased wiring loss.

The calculated results of the cooling capacity and input power are presented in Fig. 4. It is shown that the cooling capacity and input power increase as the operating speed increases. At higher speed operation, the increase ratio of input power is higher than that of cooling capacity.

Efficiency variation curves with operating speed are shown in Fig. 5. Volumetric efficiency, η_v, decreases as the operating speed deviates from a optimal operating speed. The major reason of the volumetric efficiency drops at lower speed is that the leakage ratio increase as shown in Fig. 2. The volumetric efficiency also decreases at higher speed because of the increased real compression ratio and increased back flow caused by delayed valve closing time. Due to the increase of the suction and discharge losses, indicated adiabatic efficiency decreases as the operating speed increases. The mechanical efficiency also decreases with operating speed because of the increase of the friction losses. COP drops at the higher and lower extremes of operating speed. At higher speed operation, COP drops rapidly while it drops slightly at lower speed. It could be inferred from efficiency curves that the motor efficiency(shown in Fig. 2) mainly affects the COP drop at lower speed operation, while the reduction of the adiabatic efficiency, η_{ad} and mechanical efficiency, η_m is the main reason for the big COP drop at higher speed.

Fig. 6 shows the valve velocity variation which is important factor related to the valve fracture. The maximum valve velocity at the time of impact on the valve stopper and the valve port increases as speed increases. This result indicates that the valve tends to fracture easily at higher speed.

To estimate the reliability of the piston-cylinder bearing contact area where the sliding motion is dominant, the value of load pressure multiplied by moving velocity(PV value) is commonly used. The PV value variation is shown in Fig. 7. Since the cylinder pressure and moving velocity increase as the operating speed increases, the PV value increases with operating speed so that the cylinder bearing reliability will be degraded.

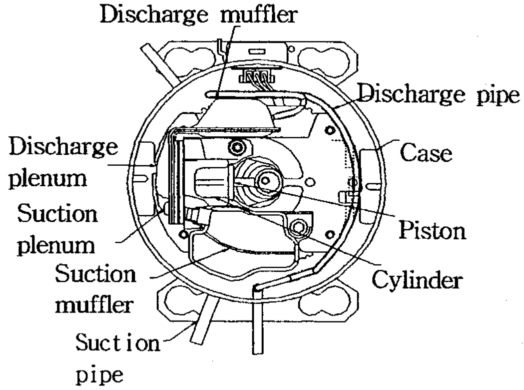
The journal center loci locates close to the bearing center as the operating speed increases as shown in Fig. 8. Fig. 9 shows that the minimum film thickness and Sommerfeld number increase as operating speed increases. These results indicate that the journal bearing is less reliable at lower speed operation. Therefore design of the journal bearing should be optimized with the consideration of journal center loci, minimum film thickness and Sommerfeld number in order to guarantee the reliability requirement. The oil pumping system, even though not studied in this paper, would be redesigned to supply sufficient oil at low speed.

CONCLUSIONS

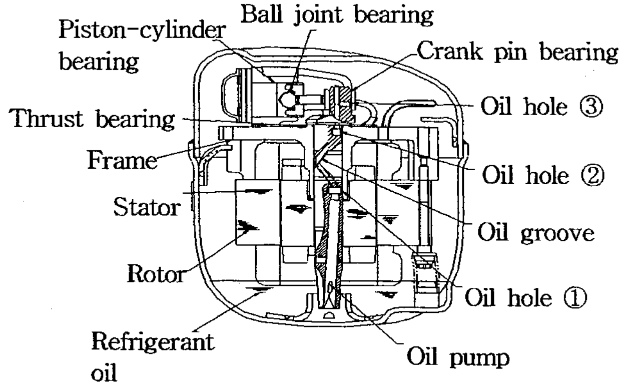
A thermodynamic and dynamic simulation of a variable speed reciprocating compressor for household refrigerator has been conducted to analyze the compressor performance and reliability variations. From the simulation results, it was found that the lower motor efficiency and higher leakage ratio at lower speed operation decrease the COP, while in higher speed operation the mechanical and valve losses decrease the COP. It is also predicted that the reliability of the valve and cylinder bearing will be worse at higher speed operation, journal bearing reliability will be worse at lower speed operation. This study shows that several design parameters must be carefully selected in order to maximize the compressor performance and guarantee the reliability of valve system and bearing system.

REFERENCES

1. R. P. Adair, E. B. Ovale and J. T. Pearson, 1972, "Instantaneous Heat Transfer to the Cylinder Wall in Reciprocating Compressors", Proceedings of the 1072 Purdue Compressor Technology Conference, pp. 521-526.
2. Manfred Krueger and Marcos Schwarz, 1994, "Experimental Analysis of a Variable-Speed Compressor", International Compressor Engineering Conference at Purdue, pp. 599-604.
3. P. K. Goenka, 1984, "Analytical Curve Fits for Solution Parameters of Dynamically Loaded Journal Bearings", Journal of Tribology, pp. 421-428.



(a) Overall view



(b) Cut view

Fig. 1 Structure of the model compressor

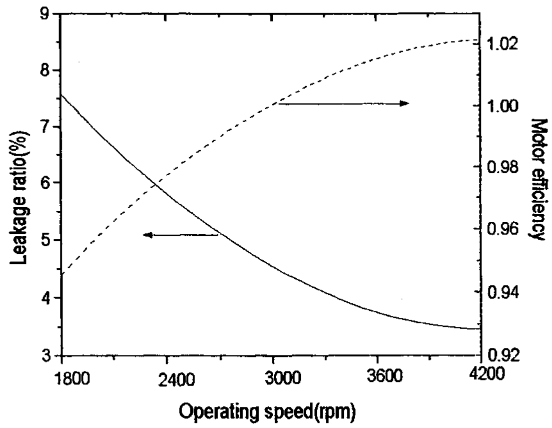


Fig. 2 Leakage ratio and motor efficiency (motor efficiency is normalized to 3000rpm)

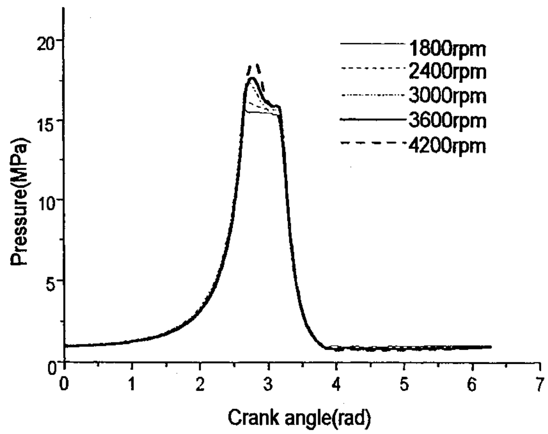


Fig. 3 Cylinder pressures

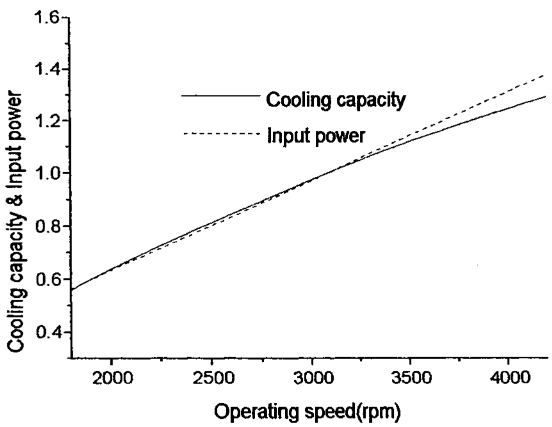


Fig. 4 Cooling Capacity and input power (Values are normalized to 3000rpm)

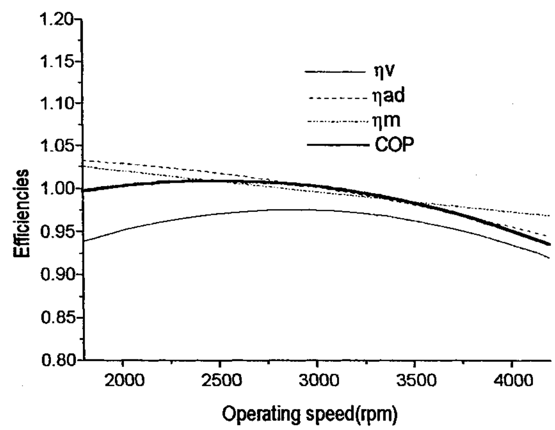


Fig. 5 Efficiencies (Values are normalized to 3000rpm)

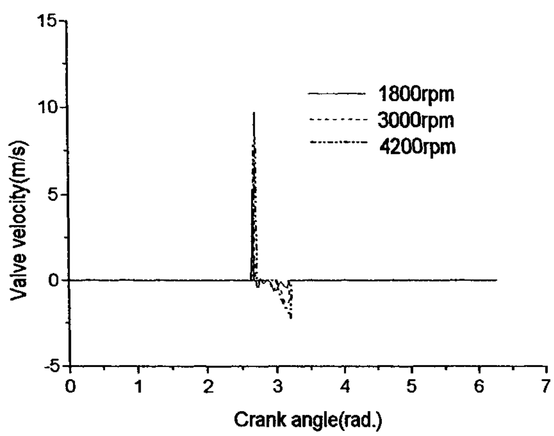


Fig. 6 Discharge valve velocity

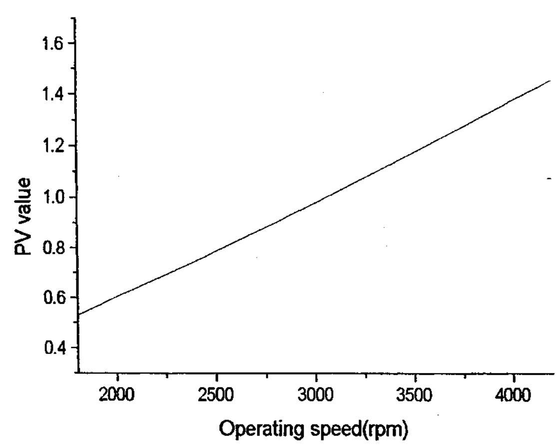


Fig. 7 PV value at piston-cylinder bearing (Values are normalized to 3000rpm)

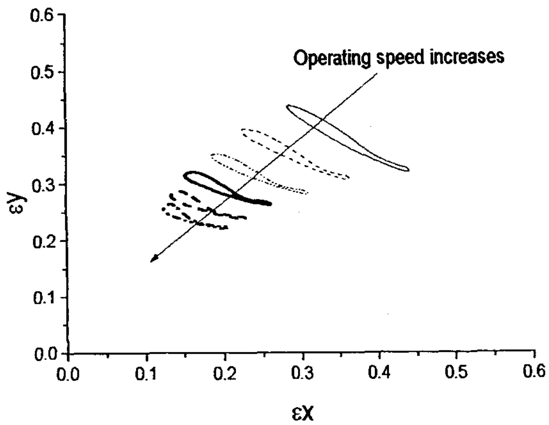


Fig. 8 Journal bearing center loci

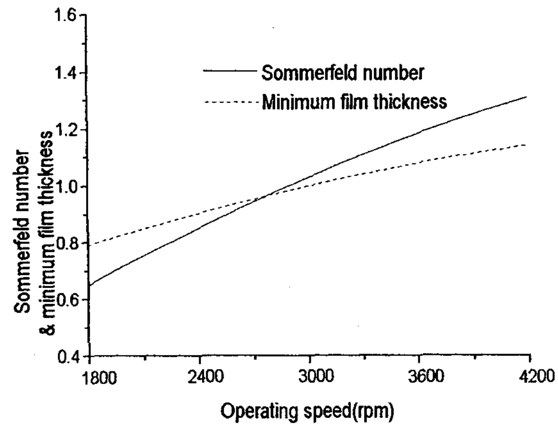


Fig. 9 Sommerfeld number and minimum film thickness
(Values are normalized to 3000rpm)